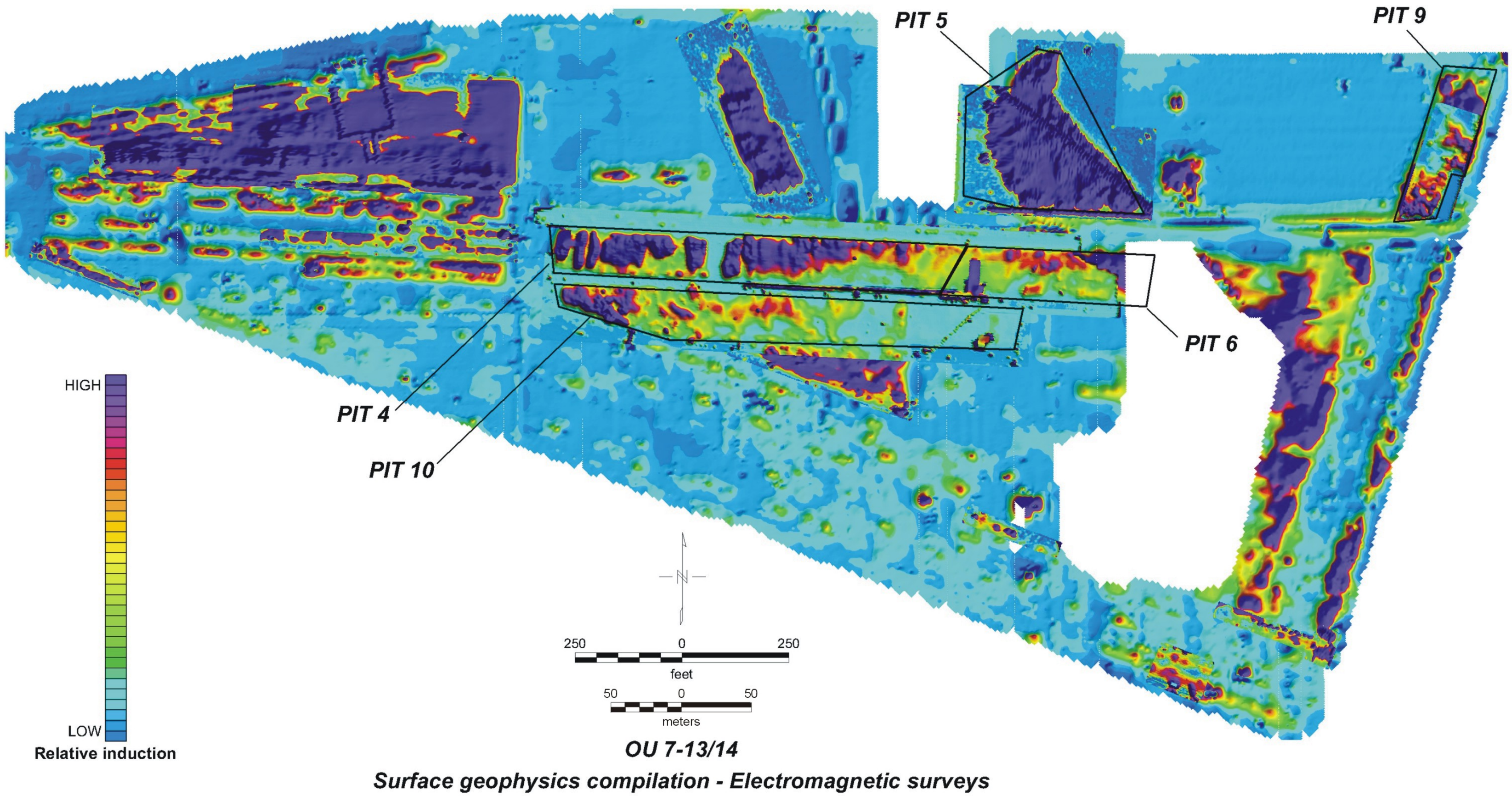

Figure 3-29. Electromagnetic geophysical survey of the Subsurface Disposal Area.

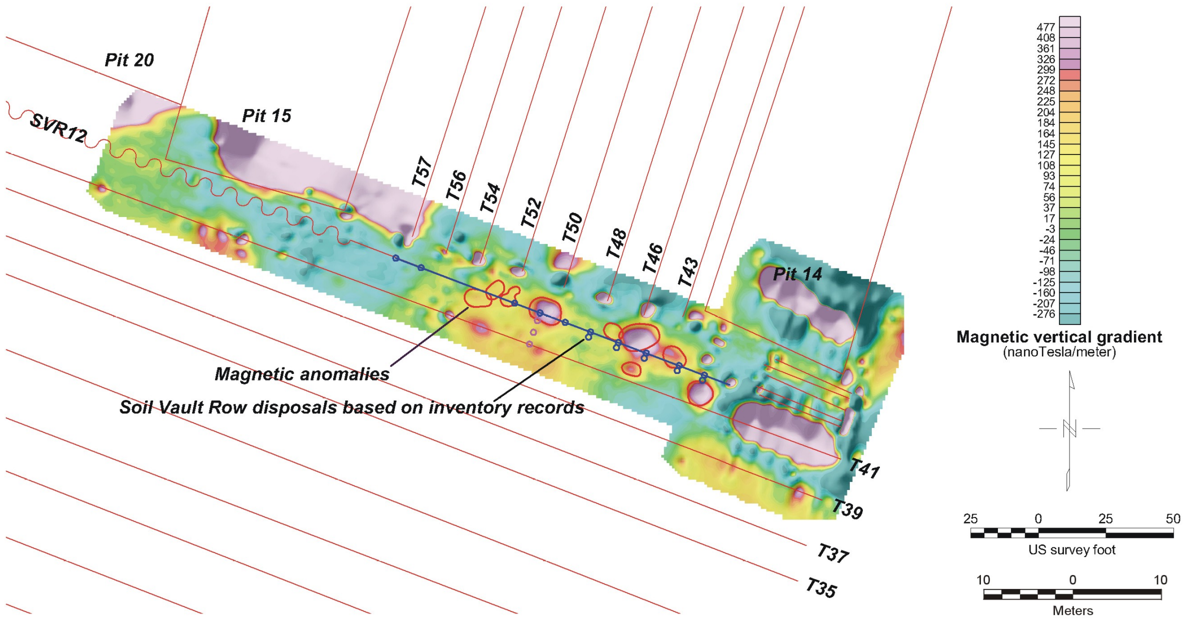

Figure 3-30. Magnetic geophysical survey for Soil Vault Row 12.

3.5.3 Identification of Areas for In Situ Treatment

Based on the success of geophysical surveys and historical disposal records to identify locations for probes for in situ characterization of buried waste, this approach was extended to targeting activated beryllium waste for focused in situ treatment (see Section 3.1.6).

Review of historical disposal records showed that approximately 19% of the total C-14 inventory buried in the SDA was associated with neutron-activated beryllium generated by INL Site reactor operations (Sebo et al. 2005). Because soil-vapor monitoring suggested that disposals of activated beryllium—but not disposals of activated stainless steel—were releasing C-14 and tritium gas (Olson et al. 2003; Koeppen et al. 2004), 15 separate beryllium disposal locations were identified for in situ treatment (Lopez and Schultz 2004). Molten paraffin grout was chosen for in situ treatment of activated beryllium because (1) C-14 and tritium releases were interpreted as evidence of corrosion of activated beryllium metal and (2) a value engineering meeting identified in situ encapsulation of activated beryllium with paraffin grout as the most effective means to stop corrosive infiltration (Shaw 2004). Figure 3-31 illustrates use of geophysical mapping and soil-gas surveys to target activated beryllium disposals for in situ treatment (Lopez and Schultz 2004). The base map layer shows magnetic anomalies for Trench 58 that indicate the position of buried iron or steel objects, perhaps including steel containers in which activated beryllium objects were buried. Positions of activated beryllium disposals, based on historical disposal records, are labeled (e.g., Be-7). In some cases, marker shipments (i.e., disposals of large metal objects) were used to align historic location estimates with geophysical mapping coordinates.

Results of soil-gas surveys are depicted as colored dots overlaid on the Trench 58 geophysical map (see Figure 3-31). Survey dots indicate the tritium concentration 0.6 m (2 ft) below ground surface. In most instances, elevated tritium concentrations are coincident with historical shipment locations and geophysical anomalies. Areas within trenches or SVRs were identified for in situ treatment if historical disposal locations exhibited geophysical anomalies or elevated soil tritium surveys. Areas identified for in situ treatment were conservative and included all adjacent areas suspected of containing activated beryllium metal (see Section 3.1.6).

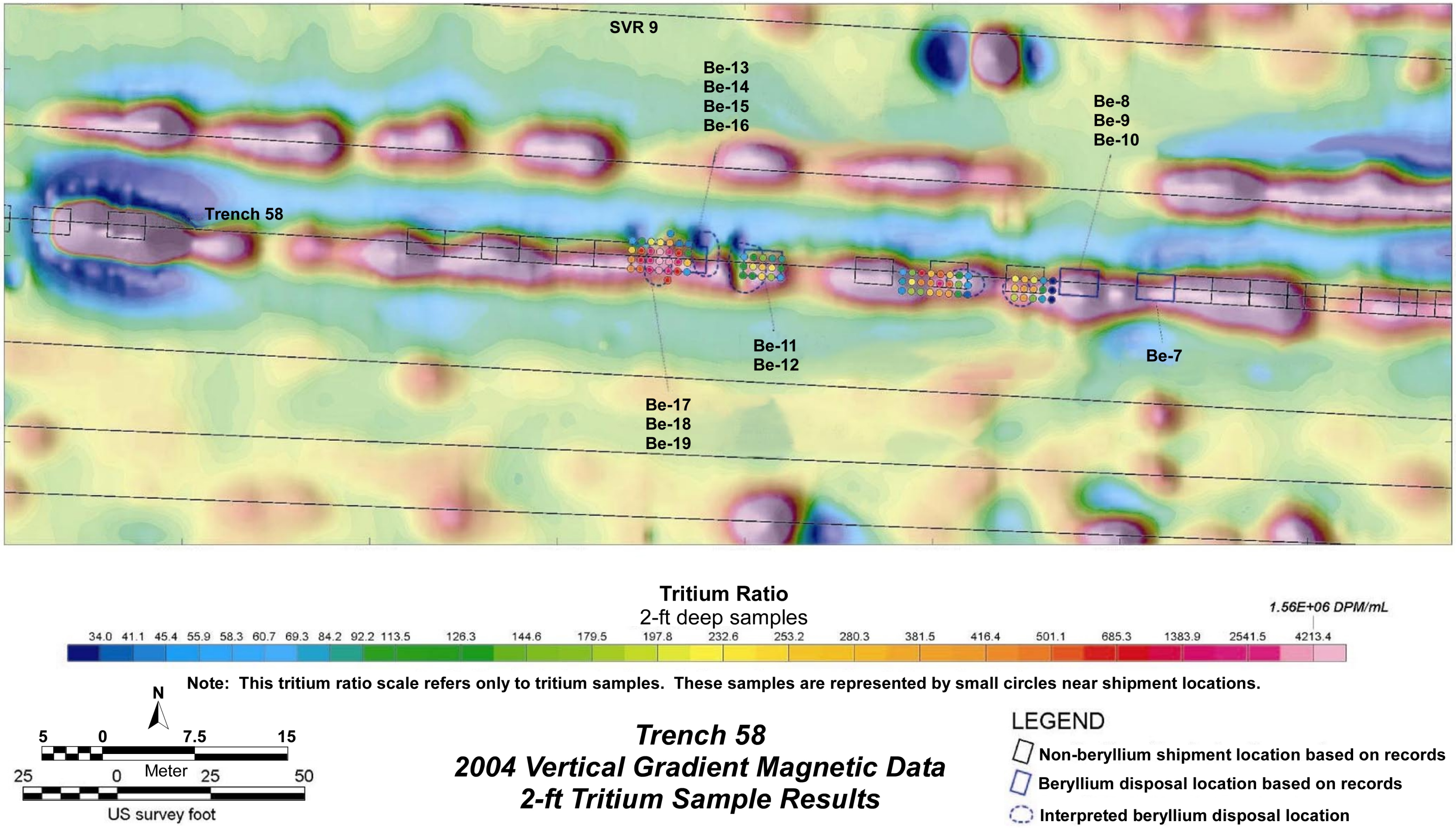

Figure 3-31. Soil-gas survey results depicted as colored dots overlaid on the Trench 58 geophysical survey.

3.5.4 Determination of Overburden and Waste Zone Thickness

Estimates of overburden thickness were developed for Pits 4, 6, and 10 using vertical gradient magnetic and electromagnetic geophysical data (Josten 2002). Table 3-29 summarizes these estimates. These estimates are based on empirical methods and apply only to buried metal objects. While the estimated average soil-cover thickness compares well with historical operating records (see Section 3.1.8), these estimates are subject to large technical uncertainties.

Table 3-29. Minimum, maximum, and average soil-cover thickness for Pits 4, 6, and 10.

Pit	Method	Number of Measurements	Minimum (ft)[a]	Maximum (ft)[a]	Average (ft)[a]	Estimate[b] (ft)
Pit 4	Magnetics	21	2.8	14.2	6.7	6 to 9
	Electromagnetic	22	2.8	8.9	6.9	
Pit 6	Magnetics	7	4.5	12.8	7.2	4 to 7
	Electromagnetic	4	6.8	10.5	8.3	
Pit 10	Magnetics	33	3.6	17.0	7.7	6 to 8
	Electromagnetic	21	2.3	7.5	5.8	

a. Josten (2002).
b. Barnes (1989).

3.5.5 Other Uses of Geophysical Analyses

Geophysical data have been used to develop an estimate of positional error for buried waste locations identified in White (2005). This estimate, coupled with an observation of orderly stacked drums during excavation of Row A in Pit 4 (see Section 3.1.5), resulted in a revision of assumptions used for mapping disposal locations in Pit 4.

Seismic refraction studies have been performed in some areas within the SDA (Hasbrouck 1989; Stoller 1995; Josten 2002, Appendix A). Results of conventional seismic refraction studies were used to estimate the depth to basalt in Pit 9 (Anderson 2003).[g] Advanced methods for analyzing seismic refraction data are presently being evaluated; these methods may allow for evaluation of waste zone thickness throughout the SDA. A means to determine thickness of the buried waste zone could greatly improve planning for future waste retrievals.

3.6 Probing in the Subsurface Disposal Area

The following subsections provide information about probing in the SDA. Some information is not yet available in published reports and is provided here in detail, while other topics are summarized.

3.6.1 Probing Background

From December 1999 through August 2004, 398 probes were installed in the SDA to collect monitoring data directly from the waste zone. Unlike monitoring equipment previously deployed in the SDA, most of these probes penetrate buried waste to provide direct or immediately proximal monitoring.

g. Note that Anderson includes seismic figures identified “EBASCO 1990,” for which no other records exist.

The probing strategy implemented in Pits 4, 5, and 10 in the SDA is described in the Operable Unit 7-13/14 Probehole Plan (Becker et al. 2000), which outlines the scope and objectives for Operable Unit 7-13/14 probing. A companion Field Sampling Plan (Salomon 2001) provides specific sampling and monitoring requirements for data collection from Type B probes. The probing in Pit 9 was conducted in accordance with requirements of the Operable Unit 7-10 Remedial Design/Remedial Action Scope of Work (INEEL 1997). The following sections address objectives of the probing strategy that determined the location of probes to meet objectives and selection of probing configurations.

3.6.1.1 Objectives of Probing. Data gathered from probes are being used to support assessment of the following parameters:

- Location of waste types, distribution of radionuclides in buried waste near the probe holes, and thickness of soil and waste layers

- Radiological fingerprints for identifying different waste streams

- Infiltration rates through the cover, buried waste, and underburden soil at the SDA

- Release rate and solubility of uranium

- Release rate of C-14

- Mass of VOC source remaining in buried waste.

3.6.1.2 Strategy of Probing. Candidate locations for waste types of interest were identified by extracting information from the WasteOScope database. White and Tedrow (2002) describe waste zone mapping and methodology for defining the shapes of shipments (e.g., ellipses, rectangles, and circles, which are indicative of locations and volumes of shipments) and estimating contaminant densities. This information, summarized by Becker et al. (2000), was used to select five focus areas. Type A probes were installed in some of these focus areas during the first phase of the SDA Probing Project. Results from nuclear logging of Type A probes in the first phase then were used to determine the location for most of the clusters of Type B probes in the second phase.

These five focus areas (i.e., Pits 4, 5, 10, and SVRs 12 and 20) were defined to probe specific waste types. To increase the likelihood of encountering a target waste stream, Type A probes typically were installed in lines, called transects, across an area of interest. Type A probes subsequently were logged, and results were used to select optimal locations for clusters of probes (i.e., several collocated Type A and Type B probes were deployed to study contaminant and moisture conditions in specific focus areas). The primary purpose for installing probes in clusters was to acquire information about the time-to-spatial relationships of the source mass, net infiltration, and leachate concentrations.

3.6.1.3 General Locations and Configurations of Probes. Type A probes are hollow, bottom-sealed tubes that allow safe access into the waste zone with nuclear logging instruments. Type B probes are equipped with various instruments or access ports to provide additional monitoring capabilities in and immediately beneath waste. Instruments in the Type B probes include tensiometers, suction lysimeters, vapor ports, and soil-moisture detectors. A special set of transparent polycarbonate tubes for visual examination of buried waste also is classified as a Type B probe. Both Type A and B probes were installed using a sonic drill. The following quantities and types of probes were installed in the SDA:

- 191 Type A probes (excludes 10 probes not logged because of shallow completions less than 1.9 m [6.3 ft] and includes five replacements for the shallow probes)

- Type B probes, including the following accessories:
  - 66 tensiometers
  - 95 soil-moisture probe instruments (i.e., 51 physical locations for probes, including some multi-instrumented)
  - 30 vapor ports
  - 18 lysimeters
  - 10 visual probes
- 32 Geologic and Environmental Probe System (GEOPS) probes (i.e., 31 lysimeters, 1 vapor port).

The suite of probes used in this investigation is illustrated in Figure 3-32 (Hubbell et al. 2005). The following sections provide more detail about types of probes and criteria used for selecting their locations, type of probe installed, and monitoring activities. An entire suite of deployed Type B probes is represented in Figure 3-33; however, most probe clusters did not include every available type of probe.

Specific types of probes and various configurations of probe placement in specific areas of the SDA are discussed in the following sections:

- Section 3.6.4—Pit 9 Study Area
- Section 3.6.5—Depleted Uranium Focus Area in Pit 10
- Section 3.6.6—Organic Sludge Focus Area in Pit 4
- Section 3.6.7—Americium and Neptunium Focus Area in Pit 10
- Section 3.6.8—Uranium and Enriched Uranium Focus Area in Pit 5
- Section 3.6.9—Activated metal investigations at SVR 12 and 20
- Section 3.6.10—Waste Zone Moisture Monitoring Array.

3.6.2 Type A Probes and Logging Instruments

Type A probes have a sealed steel casing with a 14-cm (5.5-in.) outside diameter and are installed directly into buried waste in the pits. A total of 191 Type A probes were installed in the SDA. Soil and waste adjacent to the Type A probes were characterized with nuclear logging instruments. The first sets of Type A probes were installed in lines, called transects, and spaced approximately from 1.8 to 2.1 m (6 to 7 ft) apart. Many Type A probes were successfully driven to the underlying basalt, while some Type A probes met refusal at an interim depth in buried waste. Subsequently, additional Type A probes were installed between some of the original transects to form a grid, and close-spaced Type A probes were installed in clusters around original Type A probes to evaluate source characteristics.

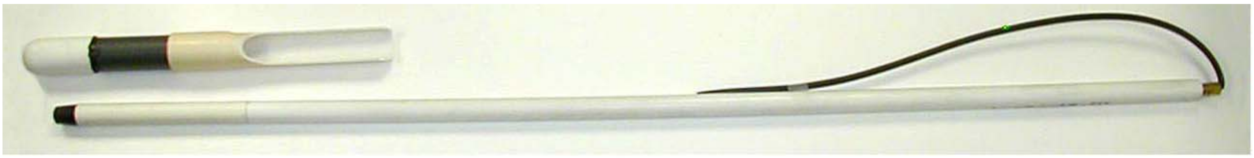

Figure 3-32a. Advanced tensiometer.

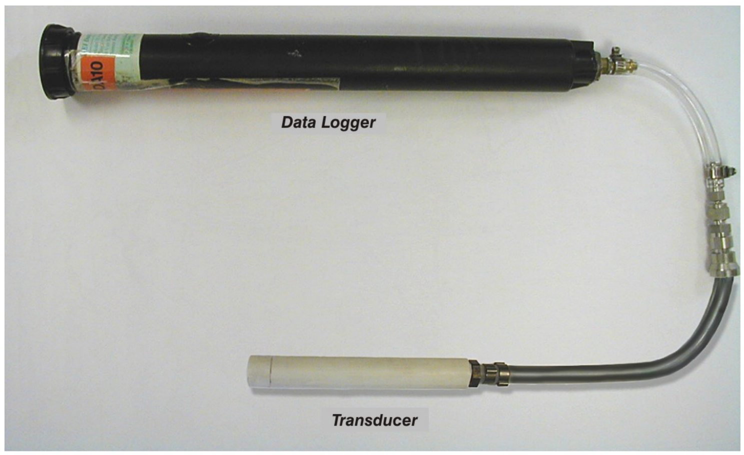

Figure 3-32b. Water-level transducer and data logger.

Figure 3-32c. Soil-moisture resistivity probe.

Figure 3-32d. Direct-push Type B tensiometer.

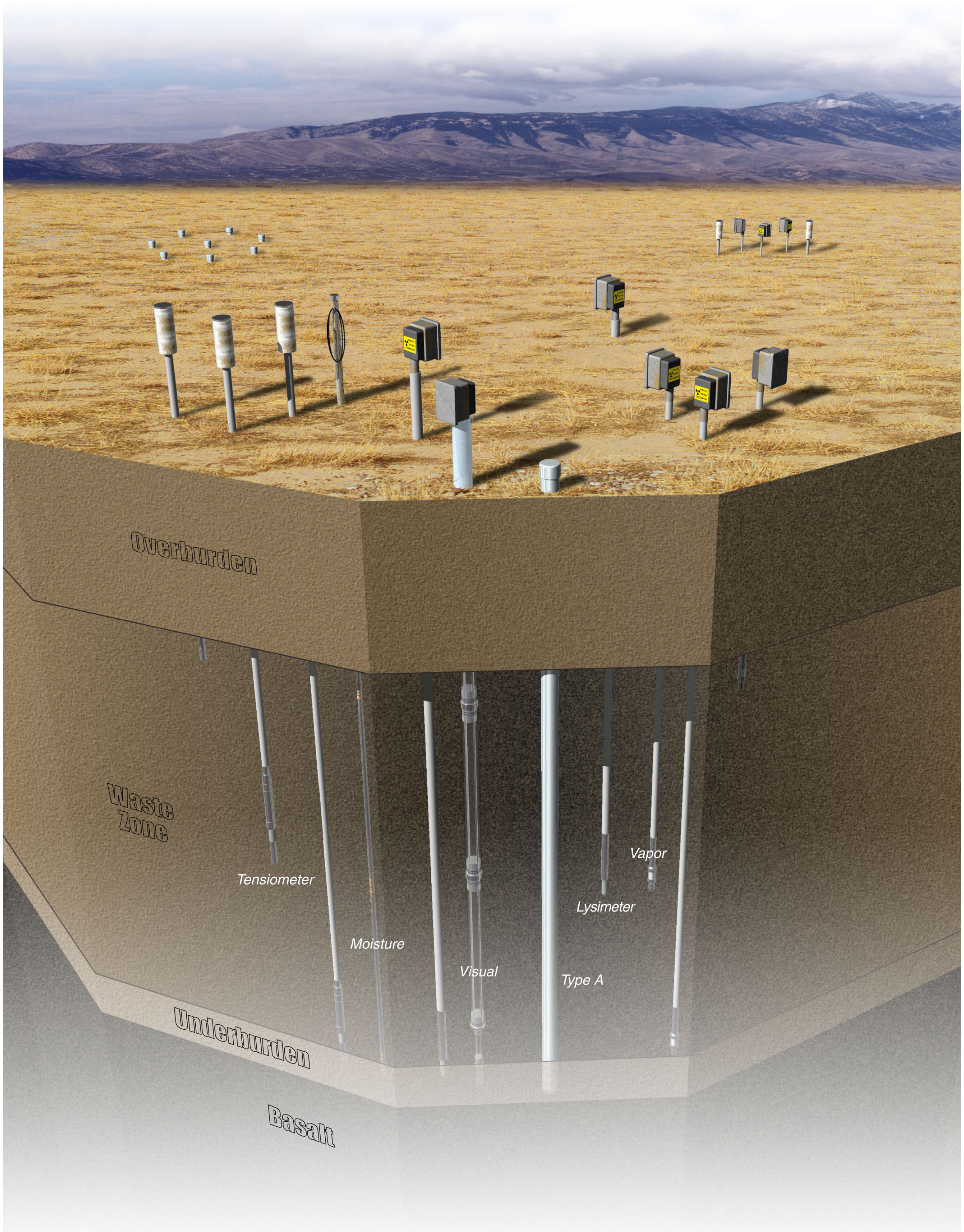

Figure 3-33. Typical probe suite deployed in the Subsurface Disposal Area.

Type A probes were monitored with the following five commercially available logging instruments:

- Passive spectral gamma detector for identifying gamma-emitting radionuclides
- Neutron activation instrument to detect prompt gamma rays from neutron activation of Cl-35, an indicator for halogenated hydrocarbons (e.g., chlorine-containing VOCs, such as carbon tetrachloride)
- Neutron-neutron detector to evaluate soil moisture
- Passive neutron detector for sensing spontaneous fission and alpha-neutron reactions (e.g., TRU constituents)
- Shielded, directional gamma detector to identify azimuthal location of gamma-emitting sources.

Detailed descriptions of these tools are presented in Becker et al. (2000) and results of the logging are given in Meyer et al. (2005). Section 4 summarizes results and interpretations of nuclear logging in the waste zone for specific contaminants.

3.6.3 Type B Probes and Instrumentation

Installation and monitoring of Type B probes followed the Field Sampling Plan (Salomon 2001) and is described by Meyer et al. (2005) in the final report for the Waste Area Group 7 Probing Project. Type B probes include tensiometers, suction lysimeters, vapor ports, soil-moisture detectors, and visual probes. Though geochemical probes were originally specified (Becker et al. 2000), the instruments did not meet development criteria, and their use was discontinued. Instead, lysimeters and vapor ports were used to collect data for evaluating oxidation-reduction conditions. The remainder of this section briefly describes various Type B probe instruments and types of data generated by the Type B probes.

3.6.3.1 Tensiometers. Tensiometers measure either matric potential of a porous medium under unsaturated conditions or pressure head if saturated conditions form. Tensiometers were placed in locations to (1) provide data on the variability of moisture in the waste zone, (2) quantify the amount and timing of moisture infiltration, and (3) define the presence and extent of saturated conditions (Salomon 2001). Construction and design specifications of the tensiometers are described in Grover (2001).

A total of 66 tensiometers were installed throughout the SDA in nested groups of three. The upper group was placed near the overburden and upper waste contact, the middle group was placed in the upper third of the waste zone, and the lower group was placed at the underburden and waste contact or in contact with the underlying basalt, as conditions allowed. In most instances, tensiometers were paired with soil-moisture probes. Data generated by these instruments were collected on data loggers, typically taking measurements at 2-hour intervals.

3.6.3.2 Soil-Moisture Probes. Soil-moisture probes indirectly measure the moisture content of soil using the relationship between the soil dielectric constant and the moisture content. Probes also perform resistivity measurements of electrical contrasts between different geologic media and indicate the temperature of surrounding material. Specifications of soil-moisture probes installed for this investigation are detailed by Anderson (2001).

A total of 51 soil-moisture probes were installed in the SDA with 95 soil monitoring instruments, some of which have multiple instruments attached. Some probes have as many as three soil-moisture instruments installed. In most instances, soil-moisture probes were paired with tensiometers. Probes often were nested in groups of three. The upper instruments were placed near the overburden and waste contact, the middle instruments were placed in the middle of the waste zone, and the lower instruments were placed at the underburden and waste contact or in contact with the underlying basalt, as conditions allowed. Soil-moisture probes are used to describe the following characteristics (Salomon 2001):

- Relative changes in moisture over time to corroborate and supplement matric potential measurements from tensiometers

- Extent of infiltration to corroborate and supplement matric potential measurements

- A lower-bound order of magnitude for net infiltration and drainage at the depth of the probe.

3.6.3.3 Lysimeters. Suction lysimeter probes collect soil-moisture samples by applying a partial vacuum to a porous cup that is in contact with soil. Construction and design specifications of suction lysimeters installed for this investigation are described by Clark (2001a). Lysimeter probes typically were installed in pairs, with one probe installed in or just below the targeted waste for that area and the other installed at the waste and underburden contact or at contact with underlying basalt.

A total of 18 lysimeter probes were installed (i.e., 16 in Pits 4, 5, and 10 and two near SVR 12). Analytical suites for lysimeter samples are described in the Type B Probe Field Sampling Plan (Salomon 2001). Samples collected from pits are analyzed for a broad range of radionuclides, VOCs, nonradioactive metal, and other inorganic constituents, depending on available sample volume. Lysimeter samples collected near soil vaults are analyzed for a smaller suite of radionuclides to focus on those typically associated with activated metallic waste.

3.6.3.4 Geologic and Environmental Probe System Lysimeters. An improved lysimeter or vapor port, GEOPS, was developed in FY 2004. The GEOPS overcomes some limitations of the original Type B lysimeter (e.g., inability of the Type B probe to rewet the porous stainless steel at the probe tip). The GEOPS also is more versatile and easily doubles as a vapor port. The primary difference between the original Type B probe and the GEOPS probe (referred to during the first year of development as the Type B+) is that the original lysimeters were built to be part of the probe string. Type B lysimeters were installed immediately above the tip and were built, at substantial expense, to withstand the same force as the casing above the instrument. The GEOPS incorporates a receiver within the tip, with normal probe casing above the tip all the way to ground surface. Once in place, a much less expensive instrument is lowered by hand and locked into the receiver in the probe tip.

Thirty-two GEOPS probes were installed within the SDA. One casing string in Pit 5 deviated after placement in such a way that the instrument could not be installed all the way to the tip. Therefore, the instrument was removed, and the casing serves as a modified vapor port.

3.6.3.5 Vapor Ports. Commercially available vapor ports were combined with Type B probes and installed to collect soil gas from waste zones and the area surrounding soil vaults in the SDA. Specifications of vapor ports installed for this investigation are described in detail by Clark (2001b). Vapor ports usually were bundled in threes and installed generally at the following three vertical horizons:

- Just below the overburden and waste contact
- Middle of the waste zone or close to a desired source in the waste
- Slightly above the waste and underburden contact.

A total of 30 vapor ports were installed (i.e., 16 in Pits 4, 5, and 10 and 14 near SVRs 12 and 20). One vapor port in Pit 4 malfunctioned and subsequently was abandoned. Samples collected from pits are being analyzed in accordance with Salomon (2001). All vapor samples from pits are analyzed for VOCs. In addition, some vapor samples are analyzed to evaluate subsurface reduction and oxidation (redox) conditions by assessing oxygen, carbon dioxide, hydrogen, and methane. All samples collected from vapor ports surrounding soil vaults are analyzed for C-14. Samples collected at SVR 20 also are analyzed for tritium.

3.6.3.6 Visual Probes. Visual probes were installed to allow observation and investigation of the soil overburden and waste zone. Visual probes are transparent polycarbonate tubes reinforced with an internal steel cage. A miniature video camera is lowered through the probe to observe waste and subsurface conditions. The videos are interpreted by personnel familiar with historical waste-generating processes (e.g., Rocky Flats Plant and historical waste disposal operations at RWMC).

Construction and design specifications of visual probes installed for this investigation are described by Clark (2001c). Visual probe video logs, with other probing data, are used to evaluate conditions in the waste zone. The following subsurface conditions can be observed:

- Location of the top and bottom of the overburden and underlying sediment
- Thickness of sediment beneath the waste
- Relative grain size of geologic media (i.e., cobbles, pebbles, sand, silt, and clay) next to the probe
- Stratification in the sediment beneath the waste or disturbance in the sediment
- Color of sediment beneath the waste for oxidation and reduction indication
- Amount of sediment vs. waste adjacent to the tube in the waste zone
- Visual indication of moisture movement
- Evidence of how tightly the tube is sealing
- Condition of the drums
- Void spaces caused by drum placement or lack of material

- Presence of cellulose material (i.e., boxes, wood, and paper)

- Waste form identification (e.g., sludge, graphite, combustibles, nitrate salt, or noncombustibles).

Video logs improved with each video. After being video-taped, the visual probes were abandoned.

3.6.4 Pit 9 Study Area

Operable Unit 7-10 comprises Pit 9, which was an active disposal pit from November 1967 through June 1969 (see Section 3.2.10). Pit 9 is approximately 4 ha (1 acre) in area and is roughly trapezoidal in shape with areal dimensions of 115 × 40 m (379 × 127 ft) (McClellan, del C. Figueroa, and King 1991).

A total of 49 Type A probes (excluding five probes with shallow penetrations) and three Type B visual probes were installed in Pit 9 (see Figure 3-34). The approach to probing in Pit 9 is described in the Remedial Design/Remedial Action Scope of Work (INEEL 1997) and is summarized in the following paragraphs:

- **Pit 9 Preliminary Campaign—**The Pit 9 preliminary campaign, conducted in June 1999, involved installing and logging three Type A probes outside the southeastern boundary of Pit 9 (i.e., Probes TP-01 through TP-03). Moisture and n-gamma logging were conducted in these probes to assess general soil conditions with particular emphasis on soil moisture (Becker et al. 2000). The Pit 9 preliminary probing campaign was undertaken to help address safety concerns before probes were installed in waste areas.

- **Pit 9 40 × 40-ft Campaign—**An area in Pit 9, measuring approximately 12 m (40 ft) on each side, was selected for detailed subsurface investigation (i.e., Probes P9-01 through P9-20) (see Figure 3-34). Known as the 40 × 40-ft study area, the location was selected based on waste inventory information and surface geophysical data assessed using the WasteOScope database. Records indicated that the area contained a high percentage of drums containing plutonium from Rocky Flats Plant. Twenty Type A probes were installed and logged using the full suite of geophysical logging tools, including several azimuthal logs. The primary objective of analyzing logging data was to select a location in the 12 × 12-m (40 × 40-ft) area to perform a limited excavation and waste retrieval (Beitel et al. 2000; Josten and Okeson 2000).

- **Pit 9 Campaign 1—**Pit 9 Campaign 1 involved installing eight additional Type A probes north of the 12 × 12-m (40 × 40-ft) area (i.e., Probes P9-21 through P9-28) to evaluate conditions in the northern part of the pit. This area was a candidate location for Pit 9 waste excavation and retrieval. Five probes could penetrate no further than depths of 1.5 m (5 ft) or less and were replaced by new probes located several feet away. All Campaign 1 probes were logged with the full standard logging suite.

- **Pit 9 Campaign 2—**Pit 9 Campaign 2 consisted of two Type A probe arrays, one located in the northern part of Pit 9 and one located along the southeastern pit boundary. The northern array included eight probes and was intended to explore for Pu-239-bearing HEPA filters. These probes have “P9-Fl-xx” designators in Figure 3-34. The southern array consisted of seven probes and was intended to explore for Pu-239-bearing graphite molds, and the probes are shown with “P9-GR-xx” designators in Figure 3-34. Both search locations were selected by the combined use of waste inventory records and surface geophysical data in WasteOScope. All Campaign 2 probes were logged with the full standard logging suite.

Figure 3-34. Probes installed in the Pit 9 study area.

- **Location P9-20 Investigation—**Six additional Type A probes were installed in a circular pattern around Location P9-20. Initial passive gamma logging data from the Type A probe at the P9-20 location indicated a significant zone of Pu-239. This zone had a maximum apparent concentration nearly three times the next highest Pu-239 detection in Pit 9 and an order of magnitude greater than the next highest reading for Pu-239 detection in any other Type A probe in the SDA. The specific objective of the additional six clustered Type A probes was to obtain detailed information needed to evaluate criticality potential.

    - Data from the six additional Type A probes showed a decrease of one to two orders of magnitude in Pu-239 levels than observed in the Location P9-20 probe. Furthermore, data indicated that the Pu-239 source was contained entirely in the circle of probes, and that the source volume and mass were much smaller than previously speculated. Spectral data indicated the presence of a point or small, distributed, concentrated source. This interpretation of the probe data is consistent with historical WasteOScope records that drums containing graphite molds were buried in the area. Graphite molds could have had plutonium fixed to their surfaces or wedged in cracks in the molds.

    - Three Type A probes were cut off and plugged with a temporary plug to enable laying floor joists for the Operable Unit 7-10 Glovebox Excavator Method Project building. All other Type A probes in Pit 9 were capped. Most probes are under the building, but some are exposed near the building. Eight in the northern portion of Pit 9 are capped and accessible.

3.6.5 Depleted Uranium Focus Area

Depleted uranium from Rocky Flats Plant is the dominant uranium waste form in the SDA. Depleted uranium material, called roaster oxide, was exposed to a flame and roasted (i.e., oxidized), allowing for safe shipping and storage of this otherwise pyrophoric material. Information from WasteOScope indicated that the western end of Pit 10 contained depleted uranium. Geophysical surveys indicated that metallic objects were present in this area. Type A probes were first installed along two transects in the Depleted Uranium Focus Area, and later, additional Type A probes were installed between the transects (see Figure 3-35). Probes DU-01 through DU-08 comprise the two original probe transects. Interpreted results from these probes are documented in Appendix D of Salomon (2001) and more recently by Josten (2005b).

Locations for Type B probe clusters were identified from Type A logging data (see Table 3-30). The highest concentrations of uranium detected in the Depleted Uranium Focus Area were found at Probes DU-10 and DU-14, indicating that the locations were optimal for Type B probe clusters. Type A probes then were logged using a directional gamma detector to identify azimuthal location of gamma-emitting sources in May 2001. A third cluster also was deployed in the Depleted Uranium Focus Area because geophysical logging results indicated that it was an excellent site to monitor neptunium waste. This site, Probe DU-08, is described in Section 3.6.7 (Americium and Neptunium Focus Area).

In addition, a depleted uranium source was identified in the Organic Sludge Focus Area in the eastern end of Pit 4. The highest level of U-238 detected in any Type A probe was found at Probe 743-08. This probe also was selected as the origin of a probe cluster to characterize organic sludge, and thus serves for both depleted uranium and organic sludge characterization. The primary clusters and probes used to characterize depleted uranium waste are listed in Table 3-30, which includes probes in Probe Cluster 743-08.